ISSN 1220-8841 (Print)
ISSN 2344-4959 (Online)

ROMANIAN NEUROSURGERY

Vol. XXXVI | No. 1 March 2022

Acute phase of traumatic brain injury. Overview of neuroimaging tools and significant findings

Maria Paz Bolaño-Romero,
Gustavo Gaitan-Herrera,
Daniel Galarza-Garrido,
Diana Carolina Caicedo-Posso,
N. Carolina Ordóñez-Veloza,
Cristian Javier Guerrero-Eraso,
Jesús David Hidalgo-Pasaje,
Jesús David Castillo-Martínez,
Sebastian Pinzon-Vargas,
Michael Gregorio Ortega-Sierra

DOI: 10.33962/roneuro-2022-011

Romanian Neurosurgery (2022) XXXVI (1): pp. 62-69
DOI: 10.33962/roneuro-2022-011
www.journals.lapub.co.uk/index.php/roneurosurgery

Acute phase of traumatic brain injury. Overview of neuroimaging tools and significant findings

Maria Paz Bolaño-Romero[1,2], Gustavo Gaitan-Herrera[2], Daniel Galarza-Garrido[2], Diana Carolina Caicedo-Posso[3], Nathalia Carolina Ordóñez-Veloza[4], Cristian Javier Guerrero-Eraso[5], Jesús David Hidalgo-Pasaje[6], Jesús David Castillo-Martínez[7], Sebastian Pinzon-Vargas[8], Michael Gregorio Ortega-Sierra[2]

[1] Grupo Prometheus y Biomedicina Aplicada a las Ciencias Clínicas, School of Medicine, Universidad de Cartagena, Cartagena, COLOMBIA
[2] Medical and Surgical Research Center, St Mary's Medical Group, Cartagena, COLOMBIA
[3] School of Medicine, Universidad Icesi, Cali, COLOMBIA
[4] School of Medicine, Universidad de Manizales, Manizales, COLOMBIA
[5] School of Medicine, Fundación Universitaria San Martín, Bogotá, COLOMBIA
[6] School of Medicine, Universidad de Antioquia, Medellín, COLOMBIA
[7] School of Medicine, Universidad Nacional, Bogotá, COLOMBIA
[8] School of Medicine, Universidad de Santander, Bucaramanga, COLOMBIA

Keywords
brain injuries,
neurotrauma,
cerebral haemorrhage,
skull fractures,
tomography,
traumatic brain injury

Corresponding author:
Michael Gregorio Ortega-Sierra

Medical and Surgical Research Center, St Mary's Medical Group, Cartagena, Colombia

mortegas2021@gmail.com

ISSN online 2344-4959
© Romanian Society of Neurosurgery

First published March 2022 by London Academic Publishing www.lapub.co.uk

ABSTRACT

In neurotrauma, diagnostic imaging plays a fundamental role in the early detection of treatable injuries or the mitigation of secondary injuries. Currently, the routine imaging techniques used in the setting of a head trauma patient include non-contrast computed tomography (CT), computed tomography angiography (CTA), conventional magnetic resonance imaging (MRI) with T1, T2 or diffusion imaging. Of the above mentioned, CT is superior to MRI in terms of speed of examination, due to the greater access to portable equipment in the patient's environment, which reduces the risk of secondary complications at the time of transfer to the radiology department. Nevertheless, MRI provides a much higher quality of images than CT. MRI is not indicated for the diagnosis of acute brain injury, but if the results of CT without contrast are normal, and neurological manifestations are present, it is indicated. As a result, CT should be the first study requested to the imaging service by the medical team in charge of the patient during the acute phase of the traumatic brain injury. The main objective of this review is to present some of the advantages and disadvantages offered by the different diagnostic imaging methods when approaching and managing brain-injured patients, with emphasis on the acute phase of trauma.

Introduction

The improvements in the technology have provoked a modern advent of the image analysis to establish clinical variables at different scales, so that the interpretation of these can create a very powerful diagnostic approach [1]. Diagnostic images play an important role in the detection of treatable lesions and prevention or mitigation of secondary injuries [2]. Currently, imaging techniques routinely used in the context of neurotrauma include computed tomography (CT) without contrast, computed tomography angiography (CTA) and conventional magnetic resonance imaging (MRI) with T1, T2, susceptibility or weighting diffusion [3]. Other studies exist but have minimal impact. Neuroimaging may allow for better characterization of patients for both treatment decisions, and the improved selection for clinical trials [4].

Despite its limitations, the Glasgow Coma Scale (GCS) is a practical, reliable and objective method to assess the level of consciousness. Patients are scored according to their best response in three categories (eye opening, verbal responses and motor score), and classified as mild, moderate and severe [5]. GCS is one of the most frequently used methods to identify patients that benefit from imaging studies [5]. In 2007 the Traumatic Head Injury Guide produced by NICE, replaced the head plain X-ray as the primary imaging modality for traumatic brain injury (TBI) by computerized axial tomography, which at first caused an increase in the cost of attention to the destabilization of the system; therefore, with the intention of balancing clinical benefit with costs, as well as exposure to radiation, strict criteria have been established for its realization [6]. The following are the imaging investigations used for the management of patients with TBI, their indications and relevant findings.

Methods

A bibliographic search was carried out in the databases PubMed and Science Direct and in the Google Scholar search engine using the following terms: Brain injuries, Neurotrauma, Cerebral hemorrhage, Skull Fractures, Tomography, Traumatic brain injury. Articles in English language were included, emphasizing the importance of neuroimaging for a correct approach to the patient with acute brain injury, through different studies where CT stands out as the main imaging method that allows to cover a wide range of pathologies that may go unnoticed or not be identified by other types of imaging during the acute phase. A total of 185 articles were identified, including original articles, subject reviews, systematic reviews, letters to the editor, case reports and case series. 43 articles were selected that matched the aim of the article.

Results

Plane X-rays

Plane X-ray (SR) of the head (skull) has no indication for the initial evaluation of the patient with traumatic brain injury. Even tough skull fractures are associated to brain injuries, its sensitivity is quite low and, in many instances, increase the chances of diagnostic failure. Thus, both the Centers for Disease Control and Prevention (CDC) and the practice guidelines of the American College of Emergency Physicians (ACEP) no longer recommend the use of plain head x-rays for acute traumatic injuries [3].

Hitesh et al. studied the effectiveness of plain x-rays for the identification of skull fractures and compared to CT scan, autopsies and SR and TAC. The SR eluded skull fractures by 19% and CT by 11.9%. Thus, the SR has no advantage and little benefit with respect to the CT, leads to the delay in the diagnosis of the injury and exposes the patient to unnecessary and harmful radiation [7].

Computed tomography

CT is the neuroimaging that is requested in the first instance in cases of TBI [8,9] **(Figures 1-2)**. It is superior to the MRI in terms of the speed of the examination, due to the greater accessibility to portable equipment that can be located around the patient, reducing the risk of complications secondary to transfer to radiology services. In addition, most institutions have tomographic equipment and to a lesser extent have resonators, so the initial examination is the CT scan. However, the resolution quality of the images is lower than the data offered by the MRI [8]. Computed tomography provides important prognostic predictors of severe head injury in children too [10]. At present, the head fixation frame of most CT scanners has certain limitations. the width cannot be effectively adjusted and texture is hard, so the head cannot be effectively fixed. The patient's intentional and unintentional movements cause head movements. Furthermore, the noise during CT operation also causes the test subject to be agitated to a certain extent. Once the head movement coefficient is too large, it will significantly affect the image data quality. This has forced medical workers to repeat CT scanning, which could expose patients to increased radiation doses and increase the workloads of medical and paramedical staff and machines, leading to increased costs and less efficient emergency service [11]. Current organization-specific practice involves placing the patient for observation and obtaining a repeat CT scan within 24 hours of initial imaging. This requires increased utilization of health care resources with increasing costs and potentially an increase in hospital-related adverse events and may also place a burden on patients and their families. We hypothesize that the vast majority of patients with low-mechanism closed head trauma who receive direct oral anticoagulant without abnormal initial cephalic CT findings will not have a late intracranial rebleed and, in fact, will not benefit from a prolonged hospital stay or repeat imaging [12].

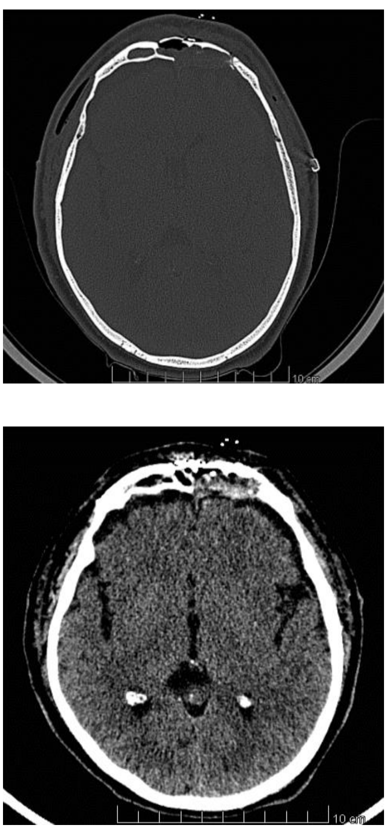

Figure 1. a, b. Computed tomography image showing skull fracture of the frontal bone

Indications: Some guidelines state that simple CT should be performed in patients with moderate or severe trauma (GSC <13) due to the higher incidence of acute intracranial hemorrhage, however different studies have shown that from 16% to 21% of patients with GCS 13 to 15 have acute intracranial hemorrhage so the CT scan should be performed [13].

Figure 2. Computed tomography image showing skull fracture secondary to a firearm

Most relevant findings: Skull fractures, hemorrhages, bruises, or cerebral edema, commonly determine the impact of the lesions on adjacent brain tissue (the mass effect, the compressed ventricle), as well as the extent and location of the injuries [6]. The main objective for the CT scan is to identify lesions can be treated by surgery, but also to monitor the patients to prevent or early identify the appearance of phenomena compatible with injuries secondary to trauma [3,7].

Skull fractures

CT Linear fractures, such as those of the groove of the middle meningeal artery, may be associated with epidural hematoma while temporal bone fractures, due to the bone lesser stiffness and the intracranial venous sinuses.

Depressed skull fractures are defined by the concavity of the affected bone, and is associated with severe complications such as hemorrhages, seizures and neuroinfection [14]. When penetrating fractures are detected, the presence of factors related to a complex prognosis should be ruled out. Basilar fractures may be missed by the CT scan, and should be suspected when facial bones fractures such as ethmoid, sphenoid, lamina cribrosa, occipital or petrous area of the temporal fractures are identified [15]. The detection of skull fracture on CT can be interpreted not only as an objective indicator of primary injury but also as a factor causing secondary damage, including the release of neuroinflammatory cytokines and coagulopathy [16]. While computed tomography plays an essential role in the management of these particular patients, there is currently no support in the literature to suggest rapid repeat imaging in this population.

There are several risk factors that may be associated with worse outcomes in the setting of depressed skull fractures. These predictors include the GCS score at presentation, fracture site, and fracture type. Fractures involving more than one area and those associated with other intracranial injuries have also been shown to worsen outcome and increase the need for surgical intervention [17].

Intracerebral hemorrhage

CT can also show us the existence or not of bruising. Brain contusions are also detected by CT. The imaging characteristics are related to the time of establishment of the lesion and the presence or absence of bleeding. They are usually located in the frontal and temporal lobes [1,8]. Acute intracranial hemorrhage appears on CT as a region of increased density owing to the linear relationship between attenuation and hematocrit, predominately owing to hemoglobin concentration [18]. With the widely used of the CT, clinicians and researchers are able to qualitatively and quantitatively describe the characteristics of a hemorrhage to guide interventions and treatments. Among these characteristics, the volume of intracranial hemorrhage is an important diagnostic indicator of stroke severity, long-term functional outcome, and mortality [19].

Extra axial hemorrhage

The epidural hematoma classically is characterized by a biconvex morphology, with location outside the axial plane and hyperdensity in the images [1,8]. The majority of patients with acute subdural hematomas have concomitant parenchymal brain injuries. The acute subdural and epidural hematomas are adequately diagnosed with CT and almost never reach the MRI room [20]. While the subdural hematomas have a semilunar appearance. Traumatic subarachnoid hemorrhages are usually located in convex areas such as cisterns [8]. The subarachnoid hemorrhage (SAH) occurs in the space between the arachnoid membrane and the pia. The most common cause of SAH is trauma. In 85% of non-traumatic cases, SAH is caused by ruptured aneurysms, while 10% fit the pattern of so-called non-aneurysmal perimesencephalic hemorrhage. The remaining 5% is due to various rare diseases, such as cocaine abuse [21]. Sources of SAH in trauma include tearing of pial vessels, extra-axial extension of a hemorrhagic contusion, and redistribution of intraventricular hemorrhage caused by damage to subependymal veins. Often the highest concentration of SAH occurs contralateral to the side of direct impact [22].

The quantitative evaluation of the data provided by the CT has not been widely studied, however, the implementation of computer-aided diagnosis technology in the measurement of injuries seems to be very promising. Some studies have shown that the quantification of midline displacement from the day of injury and the volume of bleeding correlate significantly with morbidity and mortality in severe TBI [9].

Other findings

Pathological findings in CT with poor prognosis [9]:

- Herniation
- Injury affecting several lobes
- Intraventricular or subarachnoid hemorrhage
- Injury that compromises the entire brain

There is convincing evidence that TBI increases the incidence of stroke and some epidemiological evidence that stroke outcomes are worse in patients with a history of TBI. Given the very large number of TBI that occur annually it is critically important that we determine why this population is at a greater risk for both more strokes and worse outcomes [23]. Intraventricular hemorrhage on early CT independently predicts poorer short- and long-term outcome in TBI. These findings may help guide intervention, and prognosis when intraventricular hemorrhage (IVH) is present on acute CT imaging. Evidence suggesting that IVH observed on CT may be a surrogate marker for white matter injury warrants further study with MRI imaging [24].

Magnetic Resonance Imaging

Beyond CT and MRI has proven particularly effective in identifying brain regions involved with TBI. In addition, diffusion imaging of white matter (WM) fiber pathways in blast-exposed military veterans who show no visible symptoms of injury sequelae has proven to be a useful diagnostic tool [25]. In complicated mild TBI, magnetic resonance is superior to computed tomography without contrast in diagnosing subarachnoid hemorrhages, contusions and axonal lesions. The sequences used for the TBI are T1, T2, T2-FLAIR, T2-GRE and image by diffusion [26]. Recent contributions to the body of knowledge on TBI favor the view that multimodal neuroimaging using structural and functional magnetic resonance imaging (MRI and fMRI, respectively) as well as diffusion tensor imaging (DTI) has excellent potential to identify new biomarkers and predictors of TBI outcome (27). MRI is the study of choice to further characterize intracranial hemorrhage, offering greater sensitivity in the detection of hemorrhage during all stages of hematoma evolution as well as the ability to more accurately assess the temporal evolution of hemorrhage. MRI also allows more specific investigation of the etiology of intracranial hemorrhage [18].

Indications: MRI is not indicated during the initial management of acute mild TBI. It is indicated when the results of the computed tomography without contrast are normal, and there is persistence of neurological manifestations [28]. MRI can diagnose subcortical lesions that are missed by other imaging techniques [14].

Main findings: Diffuse axonal injury (DAI) is present in a high proportion of patients with severe TBI. MRI has a greater sensitivity/specificity than CT scan for identifying DAI [1,21]. In a study by Cicuendez et al. comparing conventional MR and the diagnosis of DAI, found that the T2, FLAIR, and T2-GRE sequences provide the best visualization in more than 80% of the cases. In addition, with the FLAIR sequence, the hemispheric DAI was better evidenced at the subcortical level while the T2-GRE distinguished hemorrhagic DAI. Therefore, they recommend carrying out MRI in the subacute period of a severe TBI for the accurate diagnosis of DAI, using the sequences T2, FLAIR and gradient echo [29]. Other radiological findings, such as a midline shift, epidural hemorrhage, subarachnoid hemorrhage, and the volume of the hematoma could be additional variables to account for in predicting DAI prognosis [30]. MRI allows the precise quantification, of the size of the lesions as well as, clinically useful prognostic information [28]. The disadvantages of magnetic resonance include prolonged time being a long test and the lower probability of diagnosing fractures [29].

For subacute to chronic TBI, magnetic resonance is the test of choice due to its high sensitivity for the detection of cerebral atrophy [28]. Actually, the modified ultrafast MRI protocol for brain imaging demonstrates clinically acceptable image quality in four out of five sequences and has high accuracy in diagnosing normal and clinically significant abnormalities when compared against the standard MRI protocol for brain imaging. It could potentially benefit a select group of pediatric patients who require neuroimaging [31] routine clinical use of synthetic MRI can be feasible for neuroimaging in daily practice because the overall image quality and conspicuity of anatomical details were acceptable. In addition, the two attending neuroradiologists had no significant challenge during radiologic assessment of all synthetic images.

In previous clinical studies using synthetic MRI, the synthetic images had a similar diagnostic utility with sufficient or better image quality when compared to conventional MRI scans [32]. Also, MRI and CT brain imaging may be equally accurate for detecting acute brain hemorrhages in people with acute focal stroke symptoms. However, MRI may be more accurate than CT imaging for detecting chronic brain hemorrhages [33].

Functional neuroimaging: A variant deserving mention is proton MRI spectroscopy, which evaluates metabolic and biochemical alterations in patients with TBI. The detection of different metabolites allows the diagnosis of anomalous neurometabolic profiles such as the reduction in the levels of N-acetylaspartate (NAA), NAA/choline and NAA/Creatinine. The metabolite reduction persists for weeks to months and is evident both in apparently healthy white matter tissue and in perilesional areas, even though conventional MRI does not show such structural alterations. Biochemical alterations due to neural structural deformation caused by TBI imbalances neurotransmitters release that can affect the cellular sodium–potassium (Na^{+}-K^{+}) pump and results in distribution of membrane homeostasis [34]. The advantage of this imaging tool is to allow correlation with the functional outcome by 6 months after TBI [13]. Recent meta-analysis showed that significant changes in the ratios NAA / Creatinine and Choline / Creatinine and in the absolute values of NAA are associated with clinical outcome in TBI [35].

Future perspectives

Progress in the advancement of strategies and models to improve sensitivity and specificity in the use of neuroimaging is one of the fields of radiology, neurology and neurosurgery studies with the greatest impact today [36-38]. The investment in robotic neurosurgery and the deepening of neurosurgical education during undergraduate, are objectives to be reinforced in low- and middle-income countries, in order to promote in-hospital care of patients with neurosurgical pathology and, in particular, patients with neurotrauma [39-41]. Translational research in neurosurgery, through the search for biomarkers and gene expression (currently known as neurogenomics and neuroimaging genomics), can substantially improve the diagnosis, management and prognosis of this type of patients, by improving the diagnostic accuracy and management of intervention times [41-43]. It is necessary to continue working from the global neurosurgery, to the approach of strategies that help the technological and academic development of neurosurgery in third world countries [37].

Conclusion

TC scan is the imaging test of choice for the early evaluation of TBI patients. The primary objective is to diagnose injuries amenable to surgery, and have been shown to reduce mortality. Plane head X-rays are no longer indicated. For patients suspected of harboring vascular injuries, computed tomography angiography or magnetic resonance angiography are indicated. MRI is used at a later phase of managing TBI patients and most often for the diagnosis of a diffuse axonal lesion and prognosis determination.

References

1. Su E, Bell M. Diffuse Axonal Injury. In: Laskowitz D, Grant G, editors. Translational Research in Traumatic Brain Injury. Boca Raton (FL): CRC Press/Taylor and Francis Group; 2016. Chapter 3. Available from: https://www.ncbi.nlm.nih.gov/books/NBK326722/
2. Chang WT, Badjatia N. Neurotrauma. Emerg Med Clin North Am. 2014; 32(4):889-905.
3. Shin SS, Bales JW, Edward Dixon C, Hwang M. Structural imaging of mild traumatic brain injury may not be enough: overview of functional and metabolic imaging of mild traumatic brain injury. Brain Imaging Behav. 2017; 11(2):591-610.
4. Newcombe V. Neuroimaging of TBI, moving towards 'big data' and precision management. Journal of the Neurological Sciences. 2019: 405:39-40.
5. Murray GD, Brennan PM, Teasdale GM. Simplifying the use of prognostic information in traumatic brain injury. Part 2: Graphical presentation of probabilities. J Neurosurg. 2018; 128(6):1621-1634.
6. Hodgkinson S, Pollit V, Sharpin C, Lecky F; National Institute for Health and Care Excellence (NICE) Guideline Development Group. Early management of head injury: summary of updated NICE guidance. BMJ. 2014; 348:g104.
7. Chawla H, Malhotra R, Yadav RK, Griwan MS, Paliwal PK, Aggarwal AD. Diagnostic Utility of Conventional Radiography in Head Injury. J Clin Diagn Res. 2015; 9(6):TC13-5.
8. Williamson C, Morgan L, Klein JP, Care N. Imaging in Neurocritical Care Practice. 2017; 1(212):840–51.
9. Pervez M, Kitagawa RS, Chang TR. Definition of Traumatic Brain Injury, Neurosurgery, Trauma Orthopedics, Neuroimaging, Psychology, and Psychiatry in Mild Traumatic Brain Injury. Neuroimaging Clin N Am. 2018; 28(1):1–13.
10. Ortega Rodríguez J, Costa Clar JM, Caritg Bosch J, Martín Rodrigo JM, et al, Severe head injury among children: Computerised tomography evaluation and intracranial pressure monitoring as prognostic factors. Medicina Intensiva. 2001; 25(1):8-13.
11. Wang H, Dong L, Xia B, Li Y, Pei Y, Zhang J. Letter to the Editor Regarding "What Is the Best Timing of Repeated CT Scan in Mild Head Trauma with an Initially Positive CT Scan?". World Neurosurgery. 2020; 141:552.
12. Mourad M, Senay A, Kharbutli B. The utility of a second head CT scan after a negative initial CT scan in head trauma patients on new direct oral anticoagulants (DOACs). Injury. 2021; 52(9):2571-2575.
13. Cook NF. The Glasgow Coma Scale: A European and Global Perspective on Enhancing Practice. Critical Care Nursing Clinics of North America. 2021; 33(1):89-99.
14. Vespa PM. Imaging and decision-making in neurocritical care. Neurol Clin. 2014; 32(1):211–24.
15. Al-Sarraj S. The pathology of traumatic brain injury (TBI): a practical approach. Diagnostic Histopathology. 2016; 22(9):318-326.

16. Fujiwara G, Okada Y, Ishii W, Iizuka R, Murakami M, Sakakibara T, et al. Association of skull fracture with in-hospital mortality in severe traumatic brain injury patients. Am J Emerg Med. 2021; 46:78-83.
17. Berg A, Voigt B, Kaul S. Delayed evolving epidural hematoma in the setting of a depressed skull fracture: A case report and review of the literature. Trauma Case Rep. 2019; 22:100193.
18. Saad AF, Chaudhari R, Fischbein NJ, Wintermark M. Intracranial Hemorrhage Imaging. Semin Ultrasound CT MR. 2018; 39(5):441-456.
19. Kuang Z, Deng X, Yu L, Wang H, Li T, Wang S. Ψ-Net: Focusing on the border areas of intracerebral hemorrhage on CT images. Comput Methods Programs Biomed. 2020; 194:105546.
20. Karantanas AH, Komnos A, Paterakis K, Hadjigeorgiou G. Differences between CT and MR imaging in acute closed head injuries. CMIG Extra: Cases. 2005: 29(1):1-8.
21. Vermeulen L, Goethem AV, van den Hauwe L, Beuls E, Parizel PM, Jacobs W. Pseudo-subarachnoid hemorrhage: A tricky CT finding with serious medicolegal implications. Forensic Imaging. 2021; 24:200427.
22. Hijaz TA, Cento EA, Walker MT. Imaging of Head Trauma. Radiologic Clinics of North America. 2011; 49(1):81-103.
23. Anderst J, Carpenter S, Frazier T, Appavu B, Noetzel M, Beslow LA, et al. Subdural hemorrhage in a cohort with cerebral sinovenous thrombosis: Application to abusive head trauma. Child Abuse Negl. 2021; 117:105119.
24. Atzema C, Mower WR, Hoffman JR, Holmes JF, Killian AJ, Wolfson AB, et al. Prevalence and prognosis of traumatic intraventricular hemorrhage in patients with blunt head trauma. J Trauma. 2006; 60(5):1010-7.
25. Bhattrai A, Irimia A, Van Horn JD. Neuroimaging of traumatic brain injury in military personnel: An overview. J Clin Neurosci. 2019; 70:1-10.
26. Enríquez O. Imaging in trauma. Rev Médica Clínica Las Condes. 2013; 24(1):68–77.
27. Irimia A, Wang B, Aylward SR, Prastawa MW, Pace DF, Gerig G, et al. Neuroimaging of structural pathology and connectomics in traumatic brain injury: Toward personalized outcome prediction. Neuroimage Clin. 2012; 1(1):1-17.
28. Wintermark M, Sanelli PC, Anzai Y, Tsiouris AJ, Whitlow CT. Imaging evidence and recommendations for traumatic brain injury: Conventional neuroimaging techniques. J Am Coll Radiol. 2015; 12(2):e1–14.
29. Lozada Martinez ID, Ortega-Sierra MG, Zambrano-Arenas MDP, Páez-Escallón N, Perea-Martinez DG, Caldera-Arrautt YS, et al. Essentials of cerebral fat embolism syndrome: A hidden enemy in trauma. Roneuro. 2021; 35(3):316-20.
30. Cicuendez M, Castaño-León A, Ramos A, Hilario A, Gómez PA, Lagares A. Magnetic resonance in traumatic brain injury: A comparative study of the different conventional magnetic resonance imaging sequences and their diagnostic value in diffuse axonal injury. Neurocirugia. 2017; 28(6):266–75.
31. Guarnizo A, Chung HS, Chakraborty S. Subcallosal haemorrhage as a sign of diffuse axonal injury in patients with traumatic brain injury. Clin Radiol. 2021 ;76(3):237.e15-237.e21.
32. Ahamed SH, Lee KJ, Tang PH. Role of a modified ultrafast MRI brain protocol in clinical paediatric neuroimaging. Clin Radiol. 2020; 75(12):914-920.
33. Ryu KH, Baek HJ, Moon JI, Choi BH, Park SE, Ha JY, et al. Initial clinical experience of synthetic MRI as a routine neuroimaging protocol in daily practice: A single-center study. J Neuroradiol. 2020; 47(2):151-160.
34. Kidwell CS, Chalela JA, Saver JL, Starkman S, Hill MD, Demchuk AM, et al. Comparison of MRI and CT for detection of acute intracerebral hemorrhage. JAMA. 2004; 292(15):1823-30.
35. Rakib F, Al-Saad K, Ahmed T, Ullah E, Barreto GE, Md Ashraf G, et al. Biomolecular alterations in acute traumatic brain injury (TBI) using Fourier transform infrared (FTIR) imaging spectroscopy. Spectrochim Acta A Mol Biomol Spectrosc. 2021; 248:119189.
36. Brown M, Baradaran H, Christos PJ, Wright D, Gupta A, Tsiouris AJ. Magnetic resonance spectroscopy abnormalities in traumatic brain injury: A meta-analysis. J Neuroradiol. 2018; 45(2):123–9.
37. Acevedo-Aguilar L, Gaitán-Herrera G, Reina-Rivero R, Lozada-Martínez ID, Bohorquez-Caballero A, Paéz-Escallón N, et al. Pulmonary injury as a predictor of cerebral hypoxia in traumatic brain injury: from physiology to physiopathology. J Neurosurg Sci. 2021 Nov 11.
38. Lozada-Martínez I, Maiguel-Lapeira J, Torres-Llinás D, Moscote-Salazar L, Rahman MM, Pacheco-Hernández A. Letter: Need and Impact of the Development of Robotic Neurosurgery in Latin America. Neurosurgery. 2021; 88(6):E580-E581.
39. Ortega-Sierra MG, Durán-Daza RM, Carrera-Patiño SA, Rojas-Nuñez AX, Charry-Caicedo JI, Lozada-Martínez ID. Neuroeducation and neurorehabilitation in the neurosurgical patient: programs to be developed in Latin America and the Caribbean. J Neurosurg Sci. 2021.
40. Miranda-Pacheco JA, De Santis-Tamara SA, Parra-Pinzón SL, González-Monterroza JJ, Lozada-Martínez ID. Medical interest groups and work policies as emerging determinants of a successful career: A student perspective - Correspondence. Int J Surg. 2021; 92:106020.
41. Ortega-Sierra MG, Prado-Grajales V, Martinez-Imbett R, Unás-Perea K, Lozada Martinez ID. Research career in neurosurgery: a challenge for future neurosurgeons. J Neurosurg Sci. 2021 Aug 3.
42. Blanco-Teherán C, Quintana-Pájaro L, Narvaez-Rojas A, Martínez-Pérez R, García-Ballestas E, Moscote Salazar L, et al. Evidence-based medicine in neurosurgery: why and how? J Neurosurg Sci. 2021 Aug 3.
43. Herrera-Martinez MP, García-Ballestas E, Lozada-Martinez I, Torres-Llinás D, Moscote-Salazar L. Letter to the Editor. Creating the conditions for gender equality to

end sexual harassment in neurosurgery. J Neurosurg. 2021 Feb 5:1-2.
44. Lozada-Martínez I, Bolaño-Romero M, Moscote-Salazar L, Torres-Llinas D. Letter to the Editor: 'Medical Education in Times of COVID-19: What's New in Neurosurgery?'. World Neurosurg. 2020; 143:603.